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INVESTIGATION OF THE TIME VARIATION OF SPORADIC-E LAYERS

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SUMMARY

Wind and electron density profiles have been obtained from a series of five Nike Apache rockets launched at intervals of 90 minutes between midnight and sunrise on 22 February 1968, at Wallops Island. In addition to the irregular features normally seen in the lower E-region at night the upper part of the electron density profile shows the presence of a layer, initially at 140 km, which is blanketed by the lower region. This layer gradually descends until it merges with the lower irregular region at sunrise. Preliminary analysis of the data indicate that this upper layer is described by the current theories of redistribution of ionization by neutral winds. No such relation is found in the lower portion of the E-region.

I. INTRODUCTION

The scientific objective of this contract is the investigation of the relation between the time variation of the ionospheric wind structure and the temporal evolution of the electron density profiles. The observational part of the program consisted of a series of five rocket firings during February 1968, in which the electron density profile was measured with a Langmuir probe and the winds were obtained from a vapor trail released during the descending portion of the trajectory.

Following Dungey's (Ref. 1 & 2) suggestion that layers of enhanced ionization are caused by the deflection of moving charged particles in the terrestrial magnetic field, Whitehead (Ref. 3), Asford (Ref. 4) and others, have formulated what has come to be known as the "wind-shear" theory of sporadic E. On the basis of this theory, the vertical velocity profile of ions can be determined (to within a constant that depends on unknown electric fields)from the vertical profile of the neutral wind velocity. The "wind-shear" theory predicts, in essence, that sporadic-E layers are formed where the ion velocity profile has a node and a negative gradient. From the relation between the ion velocity and the neutral wind velocity it follows that sporadic E layers should be formed where the neutral wind profile has the same properties (hence, the term "wind-shear" theory). Previously, the relative positions of observed layers of ionization have been compared to the regions of shear on observed wind profiles. It was found that some layers are associated with wind shear as predicted by the simple wind shear theory, but that others are not so located. These previous data and the relation to the current theories based on the steady state solution of the distribution equation of charge are discussed in detail in the Final Report on Contract NASW-1083 (GCA TR-67-11-N).

In the above report it was shown that the temporal variation of sporadic-E layers cannot be neglected, as is the case for the "wind-shear" theory. As a result of the incomplete description of observations offered by the steady state solution, a time dependent solution of the equation governing electron densities was developed. This solution allows study of the initial development, as well as the location of the ionized layers. A description of the time dependent solution and the appropriate methods of data analysis are included in Section II and III of this report. In Section IV, the rocket flights which comprise the observational portion of the program, are described. Finally, Sections V and VI contain preliminary discussions of a portion of the resultant data.

II. TIME-DEPENDENT REDISTRIBUTION THEORY

The variation of electron density in the ionosphere is governed by the equation of continuity:

$$\frac{\partial N}{\partial t} = - \nabla \cdot (\underline{v}N) + (q - L) + \nabla \cdot (D \nabla N) \quad , \qquad (1)$$

where N is the electron density, $\underline{v}$ the drift velocity, q and L the production and loss rates, respectively, and D the coefficient of diffusion. The quantity $\underline{v}N$ is referred to as the "induced flux", while $D\nabla N$ represents the diffusive flux. Equation (1) states that the rate of change of the electron density is diminished by the net outward flux due to drift and diffusion, increased by the local rate of electron production and decreased by the local rate of electron loss.

The occurrence of horizontal layers of enhanced ionization in the E-region (commonly referred to as "sporadic E" and designated as E_s) must ultimately result from the variation with height of one or more of the quantities $\underline{v}$, q, and L. Any theory that attributes the formation of sporadic E primarily to the vertical variation of $\underline{v}$ may be reasonably called a "redistribution theory". Several authors (Ref. 4 & 6) have contributed to the "wind shear" theory, which may be described as a "steady state" redistribution theory ($\partial N/\partial t$ is set equal to zero in Equation 1). This section considers a redistribution theory, based on a simplified version of Equation (1), which emphasizes the location and initial development of the layers of enhanced ionization.

The following assumptions are considered reasonable for middle latitudes: (1) Since the horizontal extent of E_s layers is of the order of hundreds of kilometers, the horizontal variation of all quantities may be neglected. (2) A single species of positive ions is present, hence the recombination term has the form αN^2, where α is the recombination coefficient. The loss term is then given by

$$L = \alpha N^2 \quad .$$

(The electron attachment term βN, where β is the effective reaction rate for electron attachment, will be considered negligible here.) (3) The night-time value of the production rate is negligible:

$$q \approx 0 \quad .$$

(4) The diffusion term is unimportant, except for very narrow layers.
(5) The drift velocity has a vertical component only, and this component, w, is a known, time-independent function of height.

Since layers tend to become more narrow in time, assumption (4) breaks down at a certain state of the development of a layer. Similarly, suitable time limits determine the validity of assumptions (1) and (5). Assumption (2) is probably valid above a certain height most of the time and over most of the E region at night.

These simplifying assumptions reduce Equation (1) to the form

$$\frac{\partial N}{\partial t} = - \frac{\partial}{\partial z} (wN) - \alpha N^2 \tag{2}$$

The general solution of this equation may be written in terms of the quantity M, defined as the reciprocal of the electron density:

$$M = N^{-1} \quad ; \tag{3}$$

and in terms of a characteristic coordinate ξ, defined by the differential relation

$$d\xi = dz/w(z) \quad . \tag{4}$$

Thus,

$$M(z,t) = \frac{w(z)}{w(\zeta)} M(\zeta,0) + \alpha w(z) \int_{\zeta}^{z} \frac{dz'}{[w(z')]^2} \quad , \tag{5}$$

where ζ is defined as follows: If Equation (4) is solved so that z is obtained as a function of ξ,

$$z = f(\xi) \quad , \tag{6}$$

then

$$\zeta = f(\xi - t) \quad . \tag{7}$$

Finally, $M(z.0)$ is the initial value of $M(z,t)$. It must be emphasized that (5) is a formal solution only; the definition of ζ may encounter difficulties owing to the singularities of Equation (4). The following examples are chosen to demonstrate a number of interesting conclusions.

Model 1:
$$\underline{w = w_o + w_1 z} \tag{8}$$

This may be called the "Uniform Wind Shear" model. The solution is

$$M(z,t) = e^{w_1 t} M(\zeta,0) + \frac{\alpha}{w_1} (e^{w_1 t} - 1) \quad , \tag{9}$$

where

$$\zeta = w_1^{-1} [(w_o + w_1 z) e^{-w_1 t} - w_o] \tag{10}$$

Note that if the initial density is independent of height, it remains such for all time. Thus, even a strong wind shear (of the "correct" sign) will not necessarily lead to the formation of a layer of enhanced ionization.

Model 2:
$$\underline{w = w_o + w_1 z + w_2 z^2} \quad , \quad w_1^2 > 4 w_o w_2 \quad . \tag{11}$$

In this model the vertical drift velocity varies quadratically with height and vanishes at the heights

$$z_{\pm} = - \frac{w_1 \pm \gamma}{2w_2} \quad , \quad \gamma = + (w_1^2 - 4 w_o w_2)^{\frac{1}{2}} \quad . \tag{12}$$

In terms of z_+ and z_-, the parameter w may be expressed as

$$w = w_2 (z - z_+) \quad (z - z_-) \tag{13}$$

Note that

$$\frac{\partial w}{\partial z}\bigg|_{z = z_{\pm}} = \mp \gamma \quad , \tag{14}$$

The general solution for this model is

$$M(z,t) = \gamma^{-2} \cosh^2 \left(\frac{\gamma t}{2}\right) \left[\gamma + (w_1 + 2w_2 z) \tanh \left(\frac{\gamma t}{2}\right) \right]^2 M(\zeta,0)$$

$$+ \alpha\gamma^{-2} \left\{ \frac{w_2^{\,2}}{\gamma} \left[(z-z_+)^2 e^{\gamma t} - (z-z_-)^2 e^{-\gamma t} \right] -2w_2^{\,2} t \, (z-z_+)(z-z_-) \right.$$

$$\left. - (w_1 + 2w_2 z) \right\} \quad , \tag{15}$$

where

$$\zeta = \frac{\gamma z - (2w_o + w_1 z) \tanh \left(\frac{\gamma t}{2}\right)}{\gamma + (w_1 + 2w_2 z) \tanh \left(\frac{\gamma t}{2}\right)} \quad . \tag{16}$$

Equivalently,

$$M(z,t) = \frac{w_2^{\,2}}{\gamma^2} \left[e^{\gamma t/2} (z-z_+) - e^{-\gamma t/2} (z-z_-) \right]^2 M(\zeta,0)$$

$$+ \frac{w_2^{\,2}}{\gamma^2} \frac{\alpha}{\gamma} \left[(z-z_+)^2 e^{\gamma t} - (z-z_-)^2 e^{-\gamma t} - 2t(z-z_+)(z-z_-) - \frac{(w_1+2w_2 z)}{w_2^{\,2}} \right] \tag{17}$$

Asymptotically, that is for $\gamma t \gg 1$:

$$\zeta \rightarrow z_- \tag{18}$$

$$M(z,t) \rightarrow \frac{w_2^{\,2}}{\gamma^2} \left[\frac{\alpha}{\gamma} + M\,(z_-,\ 0) \right] (z-z_+)^2 \quad e^{\gamma t} \quad , \tag{19}$$

except in the vicinity of $z = z_+$, where

$$M(z,t) \rightarrow \frac{\alpha}{\gamma} \tag{20}$$

M attains its minimum value at $z = z_+$. Hence, this is the point of highest electron density. This maximum in the electron density occurs irrespective of the initial conditions. The width of the peak at half-maximum is given approximately by

$$2\left|z_{\frac{1}{2}} - z_+\right| = 2\,\frac{\gamma}{w_2}\,e^{-\gamma t/2} \left[1 + \frac{\gamma}{\alpha}\ M(z-,0) \right]^{-\frac{1}{2}} \tag{21}$$

In the vicinity of the maximum ($z = z_+$), the ratio of the diffusion term to the recombination term is

$$\frac{D}{\alpha}\ \frac{\partial^2 M}{\partial z^2} \rightarrow \frac{2D}{\alpha}\ \frac{w_2^{\,2}}{\gamma^2} \left[\frac{\alpha}{\gamma} + M\,(z_-,0) \right] e^{\gamma t} \quad . \tag{22}$$

The diffusion term will be negligible provided

$$e^{\gamma t} < \frac{1}{2D}\ \frac{\gamma^3}{w_2^{\,2}} \left[1 + \frac{N_{max}}{N(z_-,0)} \right]^{-\frac{1}{2}} \quad . \tag{23}$$

To obtain a numerical estimate, the following values are employed:

$$\gamma = 2 \times 10^{-3}\ s^{-1},\ w_2 = 10^{-6}\ s^{-1}\ m^{-1},\ D \leqq 5 \times 10^2\ m^2 s^{-1}$$

$N\ max/N(z_-,0) = 8$. Then

$$e^{\gamma t} < 8/3 \ . \tag{24}$$

Thus, diffusion effects may be neglected until γt is approximately unity. In this example, this corresponds to 500 seconds.

<u>Model 3</u>: $\underline{w = w_o + w_1 z + w_2 z^2}$ $\quad w_1^2 < 4\, w_o w_2$ (25)

The vertical drift velocity varies quadratically with height, but it does not vanish anywhere. If w is written in the form

$$w = w_2 \left[\left(z + \frac{w_1}{2w_2}\right)^2 + \frac{\omega^2}{4W_2^{\ 2}} \right], \quad \omega = + \left(4w_o w_2 - w_1^{\ 2}\right)^{\frac{1}{2}} , \tag{26}$$

then the absolute value of w attains its minimum value at $z = - w_1/2w_2$. The general solution is:

$$M(z,t) = \omega^{-2} \left[\omega \cos(\omega t/2) + (w_1 + 2w_2 z) \sin(\omega t/2) \right]^2 M(\zeta,0)$$

$$+ \alpha\, \omega^{-2} \left\{ 2w_2^{\ 2}\ t \left[\frac{\omega^2}{4w_2^{\ 2}} + \left(z + \frac{w_1}{2w_2}\right)^2 \right] + (w_1 + 2w_2 z)\ (1 - \cos \omega t) \right.$$

$$\left. + \frac{2w_2^{\ 2}}{\omega} \left[\frac{\omega^2}{4w_2^{\ 2}} - \left(z + \frac{w_1}{2w_2}\right)^2 \right] \sin \omega t \right\} , \tag{27}$$

where:

$$\zeta(t) = \frac{\omega z - (2w_o + w_1 z)\tan(\omega t/2)}{\omega + (w_1 + 2w_2 z)\tan(\omega t/2)} \tag{28}$$

Note that

$$\zeta(\frac{2n\pi}{\omega}) = \zeta(0) = z, \qquad n = 1, 2, \ldots, \tag{29}$$

so that

$$M(z, \frac{2n\pi}{\omega}) = M(z,0) + \alpha \frac{n\pi}{\omega}\left[1 + \frac{4w_2^2}{\omega^2}(z + \frac{w_1}{2w_2})^2\right]. \tag{30}$$

The vertical velocity of this example also leads to a maximum in the electron density irrespective of initial conditions. Furthermore, the density is quasi-periodic in the vicinity of the height $z = -w_1/2w_2$, but its peak value soon becomes smaller than the corresponding value in the case of the preceding drift velocity.

In the above three examples, it is evident that the time dependence of the night-time electron density cannot be reasonably ignored. Although the location of a peak value may remain fixed, the thickness and other characteristics of a night-time E_s layer vary with a characteristic time of about an hour. Hence, a time-dependent theory is necessary for the interpretation of sporadic E observations. A method of analysis, taking into account fully the time-dependence of all pertinent quantities, and hence appropriate for the analysis of a closely-spaced (in time) series of measurements of night-time electron densities, is presented in the following section.

III. OBSERVATIONAL PROGRAM

The objective of the closely-spaced sequential measurements is the determination of the temporal variation of sporadic E and the investigation of the validity of "redistribution" theories. Specifically, the simultaneous measurement of the vertical profile of the electron density and vertical profile of the neutral wind allows the calculation of the ion velocity profile by two independent methods. One method, outlined in sub-section 1 below, utilizes the electron density data and Equation (1). The second method, outlined in sub-section 2, utilizes the neutral wind velocity data, together with a formula from the "wind-shear" theory of Axford (Ref. 4). The ion velocity profiles obtained by the two independent methods will be compared to determine the contribution of horizontal winds to the redistribution of E-region ionization.

1. Ionization Profile

In order to avoid unnecessary assumptions, Equation (1) of Section II is simplified to the extent of neglecting horizontal variations. The result is:

$$\frac{\partial N}{\partial t} = - \frac{\partial}{\partial z} (wN) + q - \alpha N^2 - \beta N + \frac{\partial}{\partial z} (D \frac{\partial N}{\partial z}) \quad . \tag{31}$$

Integrating between the limits z_o and z yields, after some rearrangement:

$$w(z,t)\, N(z,t) = w(z_o,t)\, N(z_o,t) + D(z) \frac{\partial N(z,t)}{\partial t}$$

$$-D(z_o) \frac{\partial N(z_o,t)}{\partial z_o} - \int_{z_o}^{z} dz' \frac{\partial N(z',t)}{\partial t}$$

$$+ \int_{z_o}^{z} dz' \left[q(z') - \beta(z')\, N(z',t) - \alpha(z')\, N(z',t)^2 \right] \tag{32}$$

The electron density $N(z,t)$ is measured directly. Its vertical derivative, $\partial N/\partial z$, can be calculated from the measurements. If a short time separates consecutive measurements of N, then

$$\frac{\partial N}{\partial t} \cong \frac{\Delta N}{\Delta t}, \quad \Delta N \equiv N(t+\Delta t)-N(t) \quad .$$

Accordingly, the term containing the time derivative of N can be calculated. Of the other quantities appearing in Equation (32), the diffusion coefficient D, the recombination coefficient α and the attachment coefficient β may be regarded as known. The production rate q may be equated to zero (at night), or treated as a variable parameter. The only unknown quantity on the right side of Equation (32) is $w(z_o)$, the ionization drift velocity at the reference level z_o. The term

$$w(z_o) \quad N \quad (z_o)$$

can be neglected by a special choice of z_o. If z_o is chosen sufficiently low, then $N(z_o)$ will have a negligible value. Alternatively, z_o may be chosen to coincide with a minimum of N (if such a level clearly exists), or a maximum of N. At such points, the drift velocity $w(z_o)$ vanishes for many examples of the redistribution theory. Equation (32) then is sufficient for the calculation of $w(z,t)$.

2. Neutral Wind

In its simplest form, the relation between the vertical component of the ionization drift velocity and the neutral winds is given by (Ref. 6).

$$w = w_p + \frac{\omega_i}{\nu_i} \cos X \, V_x - \left(\frac{\omega_i}{\nu_i} \right)^2 \sin X \cos X \, V_y \quad , \tag{33}$$

where ω_i and ν_i are the ion gyro - and collison frequency, X is the geomagnetic dip angle, V_x, V_y are the (geomagnetic) eastward and northward components of the neutral wind, and w_p is a constant term due to the polarization fields. The validity of Equation (33) depends on the magnitude of the ratio ω_i/ν_i. Hence, Equation (33) should be applicable below about 120 km. Above this altitude, the exact formula (not reproduced here for brevity) must be employed. If the term w_p is negligible or constant, Equation (33) provides a second determination of the ionization drift velocity profile.

The results obtained by the two independent methods will be compared, in order to check the validity of the redistribution theory of sporadic E.

IV. ROCKET FLIGHTS

Five Nike Apache rockets were fired between midnight and dawn on 22 February 1968. The launch times and other data from the telemetry records are presented in Table 1. The firings were spaced at about 90 minute intervals and each carried a combined payload to measure the electron density profile with a Langmuir probe and the wind profile by means of a vapor trail. The first four payloads ejected TMA on the downward portion of the trajectory. The fifth payload ejected a mixture of sodium and lithium vapor. All instrumentation operated well and the required data were obtained.

The peak altitude of the five Nike Apache rockets is given in Table 2. These data were obtained from radar, which yielded a complete trajectory for each vehicle. The first of the series (14.364) carried an additional experiment attached to the second stage motor. This reduced the apogee altitude by about 25 km. The greater weight of the sodium lithium canister accounts for the lower apogee of the last vehicle (14.208).

Two other payloads combining an airglow photometer and a vapor trail were scheduled to precede this series. These payloads were fabricated under NASW-1419 and were designed to test Triethylboron as a trail material and to measure the vertical profile of the 5577Å airglow emission. One payload was fired during evening twilight on February 21, and a bright vapor trail was produced. Difficulties in the photometer section of the payload caused postponement of the second firing. The payload was fired successfully during the night of 26 February and it was concluded the TEB does not produce an observable chemi-luminescent glow in the night sky.

TABLE 1

VEHICLE PERFORMANCE DATA FROM TELEMETRY RECORD

NASA Flight No.	14.364	14.365	14.366	14.367	14.208
Nike Ignition (UT)	0509:00.1	0630:00.1	0800:00.1	0930:00.1	1102:00.1
Apache Ignition (UT)	0509:22.1	0630:21.1	0800:22.4	0930:22.0	1102:21.9
50K ft. Baroswitch on (UT)	0509:24.9	0630:24.3	0800:24.9	0930:24.0	1102:25.0
70K ft. Baroswitch on (UT)	0509:28.0	0630:27.9	0800:28.3	0930:27.5	1102:28.0
TMA Release start (UT)	0513:04.3	0634:06.2	0804:02.2	0934:05.8	1105:36.8
70K ft. Baroswitch off (UT)	0515:11.7	0636:36.6	0806:43.2	0936:54.0	1108:27.6
50K ft. Baroswitch off (UT)	0515:16.2	0636:39.5	0806:47.7	0936:56.8	1108:30.4
Loss of Signal (impact) (UT)	0515:30.7	0636:50.7	0806:57.3	0937:07.3	1108:41.6

TABLE 2

APOGEE ALTITUDE FROM RADAR DATA

Nike Apache	Apogee Altitude (km)	Vapor
14.364	156	TMA
14.365	176	TMA
14.366	181	TMA
14.367	190	TMA
14.208	168	Na-Li

V. IONOSONDE OBSERVATIONS

In support of the rocket observations, ionosonde data were obtained from the J-5 at Wallops Island, operated by the Environmental Science Services Administration. Observations were performed during the nights of 21-22 February 1968, at intervals of five minutes except during the rocket flights when the observations were performed at one minute intervals.

After sunset, the first sporadic E was observed at 2115 EST. It was present at a virtual height of about 120 km in sweeps up to 2130. No sporadic E was observed at 2135, nor in subsequent sweeps up to 2300. It was observed again at 2305 and was clearly present in sweeps up to 0035. In the following sweeps up to 0205, the sporadic E was present with only a weak echo being recorded.

A high altitude echo at a virtual height of about 190 km was observed first at 0210 EST. It descended and split into multiple echoes in the following sweeps and the echoes were weak by 0310. Intensification occurred after 0445 and several echoes were visible from 0515. Weak echoes were present from 0605 to 0700 and then strong echoes to the end of the sequence at 0800.

The ionograms recorded two minutes after the launch of each rocket are shown in Figure 1. These were almost simultaneous with the passage of the rocket through the E-region. There was a horizontal separation of approximately 40 km between the location of the rocket and the ionosonde at this time.

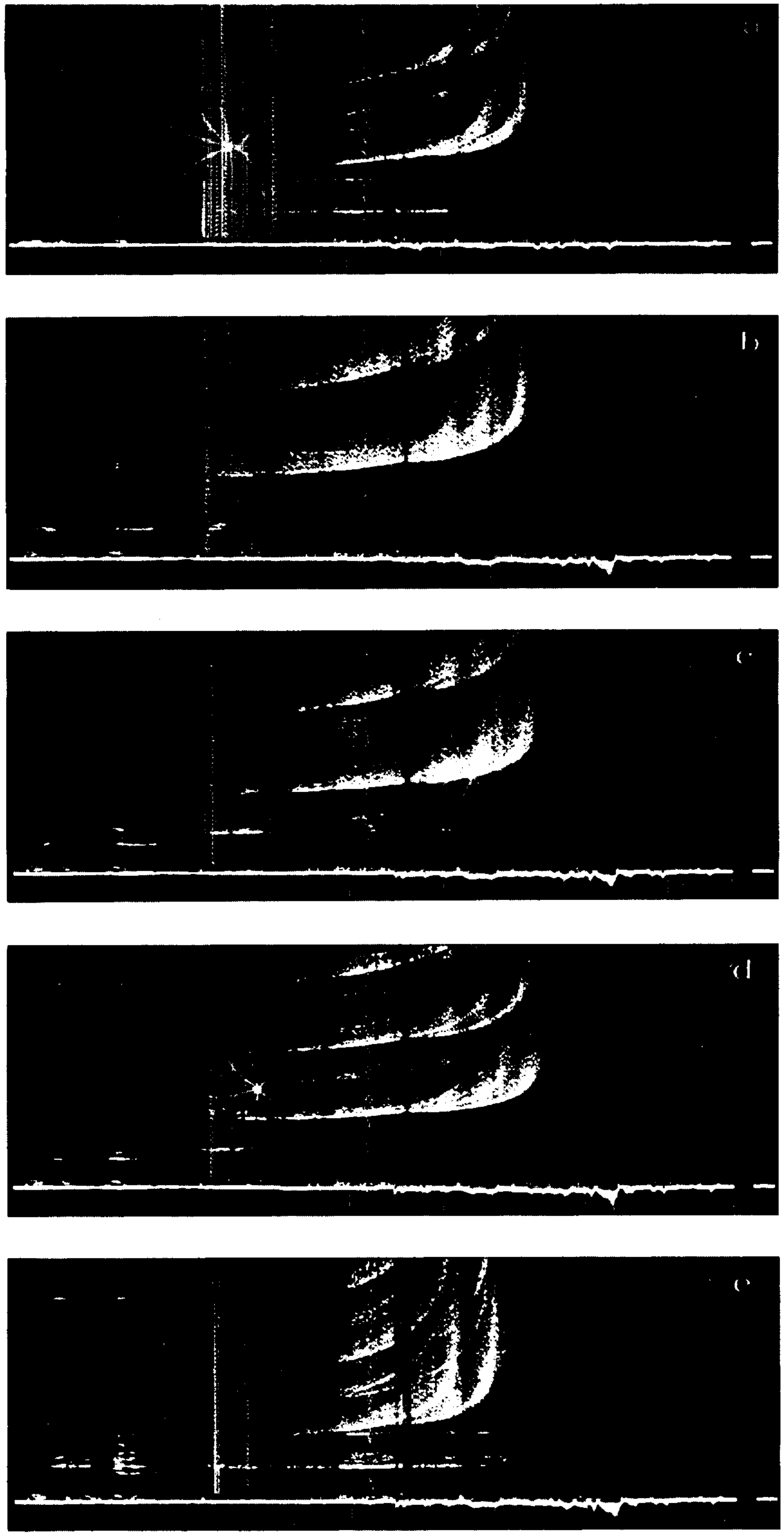

Figure 1. Ionograms recorded two minutes after rocket launch.

VI. PROBE DATA

The Langmuir probe data comprise a highly interesting sequence of electron density profiles. While several features persist through the sequence, others exhibit marked variations. The first four profiles of the series are presented in Figures 2 through 5. The heights of principal ionized layers are recorded in Table 3.

The results of a previous observation (Ref. 5), have demonstrated that the night-time E region has an irregular structure, both for a single profile and in its variation from one night to another. The lower altitude portion of the region, up to about 120 km, is characterized by a layered structure with the ratio of maximum to minimum electron density exceeding an order of magnitude. Above this region a relatively smooth profile is observed, generally having smaller electron densities than anywhere in the lower region.

The present series of profiles indicate that both lower and upper portions of the night-time E region show considerable variations in the 90 minutes between observations. Particularly striking is the occurrence of an upper layer at 140 km, which changes shape and descends in the course of the night.

The upper layer is presumably the same as the intermediate layer whose occurrence has been discussed recently by Wakai (Ref. 6). The layer is not observed in ionosonde data for quiet nights; it may, of course, be present, blanketed by the lower region. The height, from Wakai, is about 150 km except under severely disturbed conditions when it is lower, at about 130 km and is not then clearly separated from the lower region.

In the new series of electron density profiles, the upper layer is present even when an echo is not observed on the ionosonde, owing to the presence of a more intense underlying layer. The height is about 140 km in the first two profiles, but progressively lower in the succeeding profiles: 128 km then 120 km. In the final profile, the layer has practically lost its identity in the lower region where it is centered at about 110 km.

The observed neutral wind velocities were used to compute the ionization drift velocity w, as described by Axford, Cunnold and Gleeson (Ref. 7). The vertical component of the neutral wind which was not measured, but has often been shown to be small, was neglected as were the small gravitational and partial pressure terms. The computed quantity was

$$w - w_p = a_1 v_1 + a_2 v_2 \quad ,$$

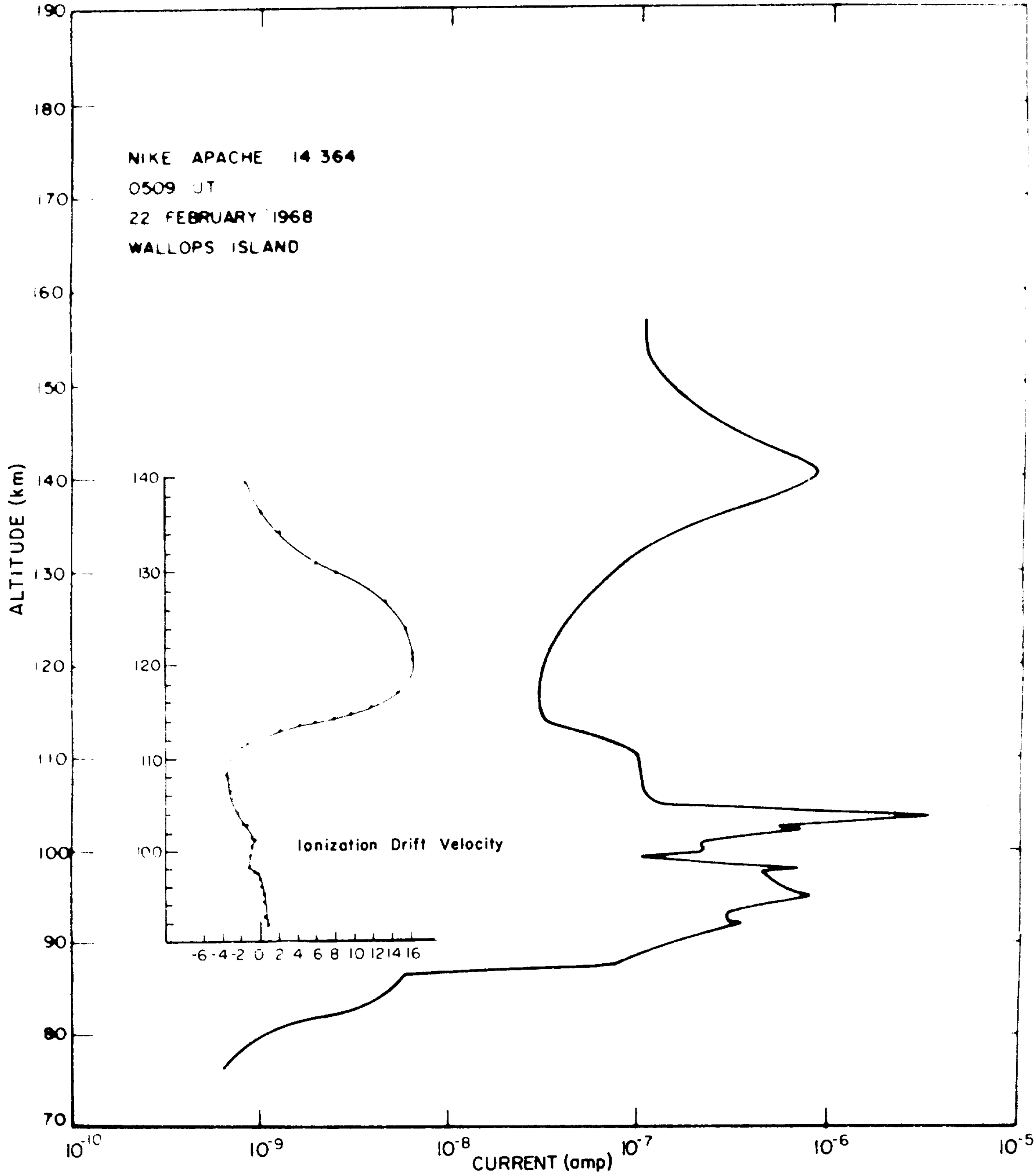

Figure 2. Profiles of probe current and ionization drift velocity for Nike Apache 14.364.

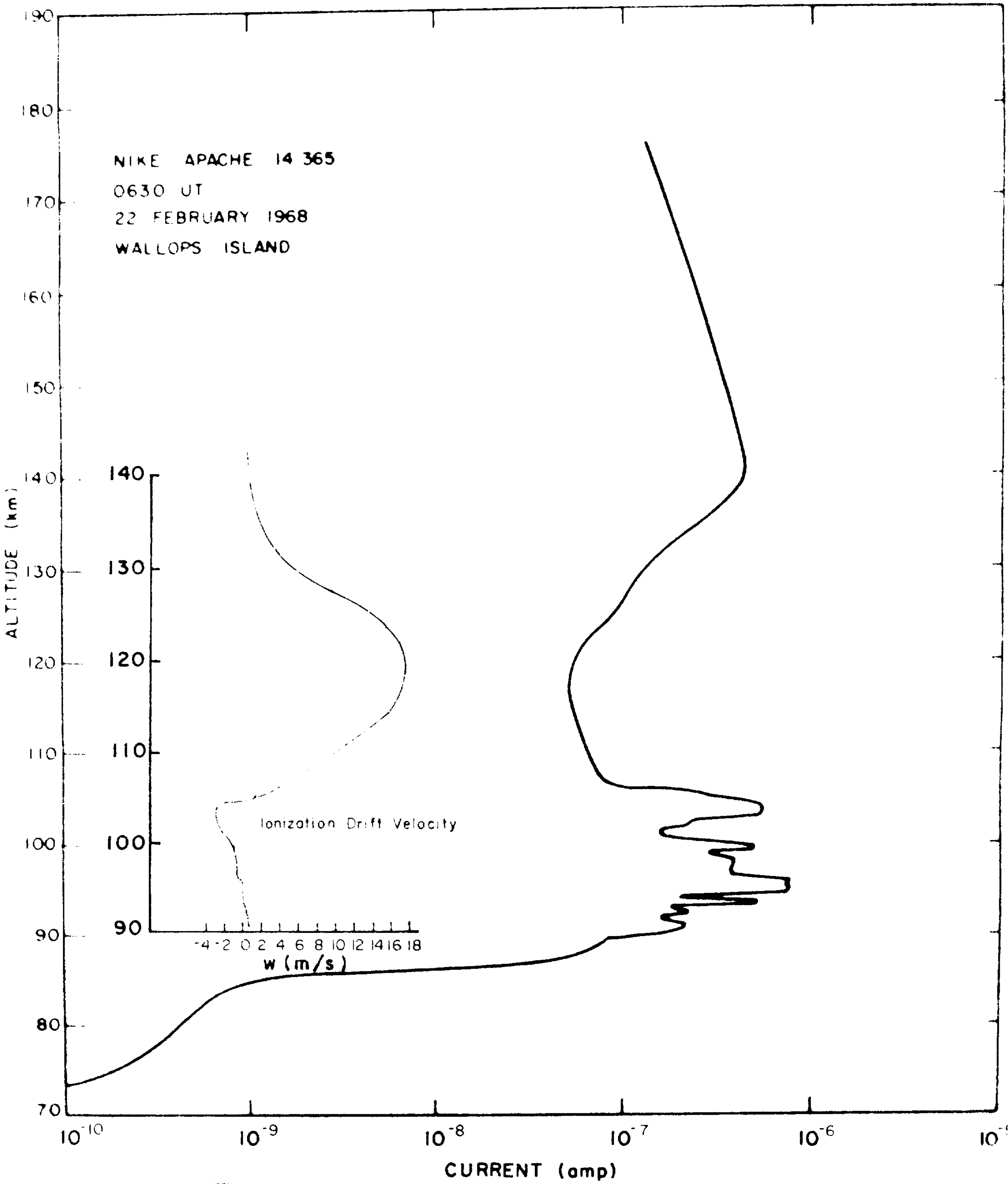

Figure 3. Profiles of probe current and ionization drift velocity for Nike Apache 14.365.

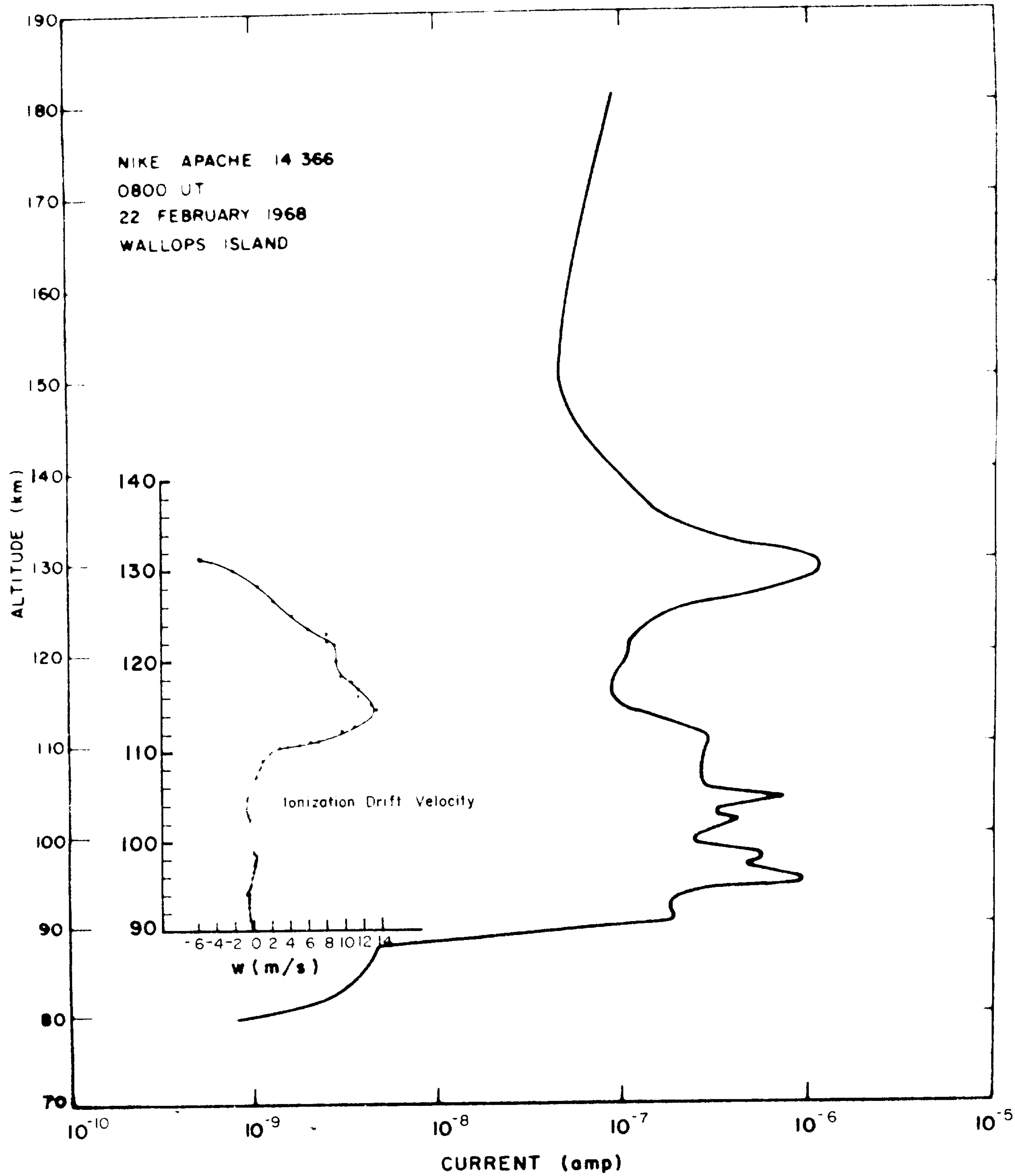

Figure 4. Profiles of probe current and ionization drift velocity for Nike Apache 14.366.

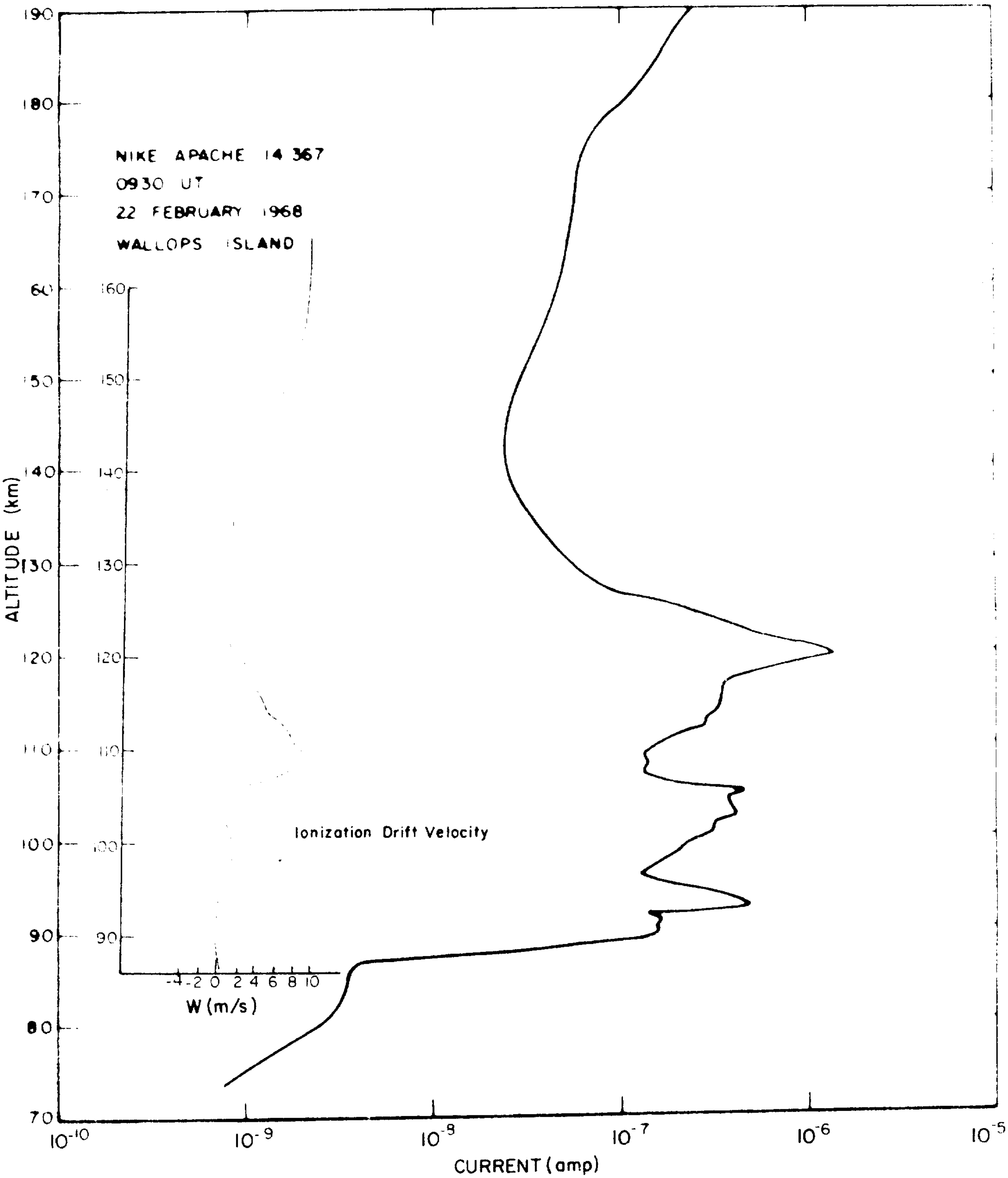

Figure 5. Profiles of probe current and ionization drift velocity for Nike Apache 14.367.

TABLE 3

PRINCIPAL LAYERS - 22 FEBRUARY 1968

Nike Apache 14.364; launch 0009 EST	
Lower Layers:	95, 104 km
Upper Layer:	140 km
Nike Apache 14.365; launch 0130 EST	
Lower Layers:	95, 104 km
Upper Layer:	140 km
Nike Apache 14.366; launch 0300 EST	
Lower Layers:	95, 104 km
Upper Layer:	129 km
Nike Apache 14.367; launch 0430 EST	
Lower Layers:	92.5, 104 km
Upper Layer:	120 km
Nike Apache 14.208; launch 0602 EST	
Layers:	92.5, 109.5 km

where w_p is the motion due to electric fields and v_1 and v_2 are the magnetically Eastward and Northward components of the horizontal winds. The coefficients a_1 and a_2 were computed, assuming the presence of electrons and one ion of mass 30. The results are included in Figures 2 through 5. The drift velocities computed from the neutral winds indicate ion convergence at the peak of the upper layer and ion divergence in the region below the peak throughout the period. The theory of redistribution of ionization by neutral winds apparently describes the motion of this layer.

The lower part of the ionization profile had the characteristics of a typical night-time E region. The primary features are the sharp lower boundary, irregular structure and high gradients. Although major regions of increased ionization may have persisted throughout the observing period, the detailed structure does not appear to be related to the smooth ion drift velocity profile. Instead, the stratified ionization profile appears to be more closely related to similar sharp features or "corners" on the wind hodographs as has been reported previously (Ref. 8).

REFERENCES

1. Dungey, J. W., The Influence of the Geomagnetic Field on Turbulence in the Ionosphere, J. Atmos. Terr. Phys. 8, 39, 1956.

2. Dungey, J. W., The Effect of a Magnetic Field on Turbulence in an Ionized Gas, J. Geophys. Res. 64, 2188, 1959.

3. Whitehead, J. D., The Formation of the Sporadic-E Layer in the Temperature Zones, J. Atmos. Terr. Phys. 20, 49, 1961.

4. Axford, W. I., The Formation and Vertical Movement of Dense Ionized Layers in the Ionosphere Due to Neutral Wind Shears. J. Geophys. Res. 68, 769-779, 1963.

5. Smith, L. G., Rocket Observations of Sporadic E and Related Feature of the E Region, Radio Science, Vol. 1, No. 2, 178-186, 1966.

6. Wakai, N., Quiet and Disturbed Structure and Variations of the Nighttime E Region, J. Geophys. Res. 72, 4507-4517, 1967.

7. Axford, W. I., Cunnold, D. M., and Gleason, L. J., Magnetic Field Variations in Temperature Zone Sporadic E Layers, Planet. Space Sci., 14, 909-916, Sept. 1966.

8. Bedinger, J. F., and Knaflich, H.B., Observed Characteristics of Ionospheric Winds. Radio Science 1, 156-168, 1966.